College of Engineering
Honors Project

Using Terrestrial Photogrammetry and GPS for More Efficient and Effective Mortgage Surveys

Submitted to

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Abstract

In today's ever changing world, there is an abundance of new technology that immerges weekly. Today it seems that almost everyone owns, uses, or has used essences of this technology in the form of cellular phones, GPS navigation systems, and digital cameras. The use of these instruments is invaluable to many of us, whether it be for work or leisure. But are these tools able to reach the required standards for measuring in engineering practices? What are the limits of this technology?

In the surveying world, photogrammetric means for obtaining data and establishing control are used daily. Aero triangulation has been around for over half a century and has changed the entire process of project design. The ability to obtain top precision from aerial photos tied in with existing ground control can not only lower costs of design, but make them much more efficient. With the introduction of GPS receivers on the plane during flight the process is even more streamline. However the transferring this process to the ground in a terrestrial format has not been covered as extensively.

In this project, the use of terrestrial photogrammetry and GPS was investigated as to its quality and reliability for mortgage surveys. These are simple, low-precision surveys that are regularly performed in Ohio.

The results indicate that a suitable instrument that combined the features of differential GPS and reliable digital imagery would be able to be used for these types of surveys.

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Acknowledgements/Dedications

I would like to acknowledge as well as dedicate this project to Prof. Bill Hazelton. Without his assistance, (even through his early and rather unnecessary farewell to the University) the completion of this project would not be possible. His years of teaching have taught me more than I ever thought possible and his dedication to his students is unmatched. Thank you for everything.

I'd like to thank his wife for the many coffee runs and the ability to keep sane through the overall annoyance that comes with being in my presence.

Finally, a thank you to his birds whose loud squawking kept me awake through endless discussion sessions.

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Introduction

Mortgage surveys are surveys performed on a parcel of land in order to determine the positions of significant features on the property with respect to the property boundaries. These features include corners of houses, shed, garages and other fixtures. The surveys themselves are fairly simple yet time-consuming. It takes a crew of at least two a significant amount of time to establish these points through the act of setting up and tearing down the equipment, making measurements and recording the data.

The purpose of a mortgage survey is to satisfy the company providing the mortgage (usually a bank) that there are no problems with the property that could ultimately cause problems should the mortgage even need to be foreclosed. This provides protection for the mortgagee and enables mortgages, and hence property transactions, to proceed quickly, efficiently and safely.

Today, digital cameras have become small, light and extremely cheap. It is possible to integrate a digital camera with a phone, providing Internet access, and a GPS receiver, allowing determination of the camera's location at the moment of exposure. It should also be possible to integrate an inclinometer and a fluxgate compass into the package, producing a basic surveying instrument in a device not much larger than a mobile phone, and at a price that would be a fraction of a conventional total station. In fact, a British company, MDL, has integrated a GPS receiver, a reflectorless laser rangefinder, a fluxgate compass, and inclinometer and a data recorder into a single, pole-like device for certain types of surveys. This device is on the market in Europe.

Some of the characteristics of mortgage surveys are that they are performed to a significantly lower standard of precision than normal boundary surveys, they are done for a relatively small margin over costs (i.e., they are not very profitable), and they are sometimes done rather poorly.

The purpose of my project is to investigate whether an alternative method of doing mortgage surveys, based on using terrestrial photogrammetry and GPS, could achieve similar if not better data collection, using less time and less manpower, than conventional methods. One object of the experimental design is to see if a future camera-based surveying instrument could be simulated and its potential performance estimated, using currently available equipment.

An additional advantage of the terrestrial photogrammetry is that a permanent photographic record of the site is obtained, which can be used for precision measurements later, should there ever be a dispute concerning the property.

Procedure

The procedure section will be broken up into two sections. The first section will deal solely with field procedures. This section will discuss all aspects of the field work from setting up for the "control" experiment to the design and reasoning behind my theoretically based experiment. The second portion will deal solely with the post processing of the data collected, explanations of equations, and the spreadsheet created to simulate a user friendly software package.

Field Work

The first half of my project was focused on the collection of field data. In order to set this up, Prof. Hazelton and I recreated what a common-or-garden variety Mortgage survey would entail. Being designated as a two man crew, we set up our back sight and began to pick up the pertinent information that would be found in this type of survey. Using a pin finder, we located all existing monumentation of the parcel, namely the property pins. Then using a "total station" and a prism we shot the location of the house and the pins. This process required two setups, one for the front and one for the back. During the switch from front to back the back sight had to be reset to get a shot from the back of the house. The following figure shows the setups in dark circles with labels of SU and back sights with labels of BS. The hollow circles are found pins.

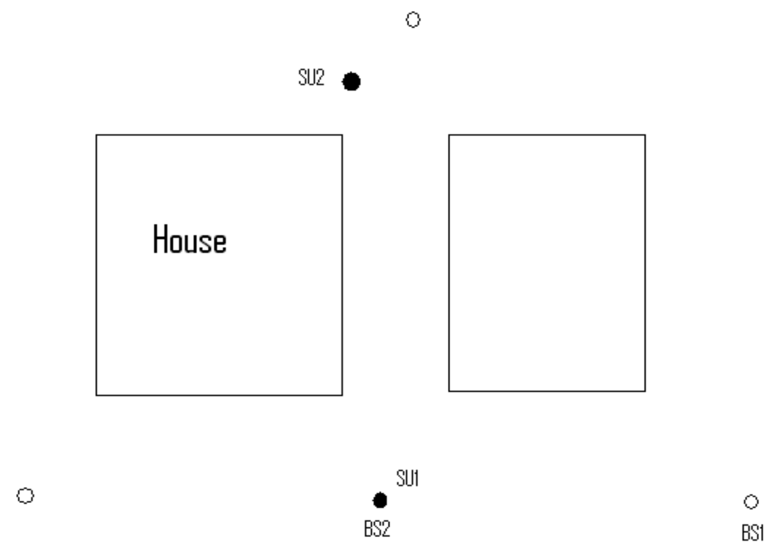

Figure 1: Field work Setup (Not to scale)

This process was timed in order to compare with the camera based survey. It took us roughly 45 min. to finish the survey, which could be translated into about 30 min. for a trained crew. After this process was complete we reset up to capture points on the house for comparisons in our camera based survey. All these points were processed and given coordinates based on a project coordinate system.

The camera based system was set up in two different ways. The first way was set up to take two existing control coordinates from the house which would be our simulated GPS receivers. The second was to take photos and shoot the location of the camera which would be the simulated GPS-camera system. The two procedures although different were designed in the same way. I would go around the building and using the super wide angle of a Sony DSC-P8 digital camera take photos of the house. As I was doing so, Dr. Hazelton would measure to the camera to get its location. The following figure shows how the project was shot. The dark circles are setups labeled SU, back sights are BS, and camera shots are diagramed as squares.

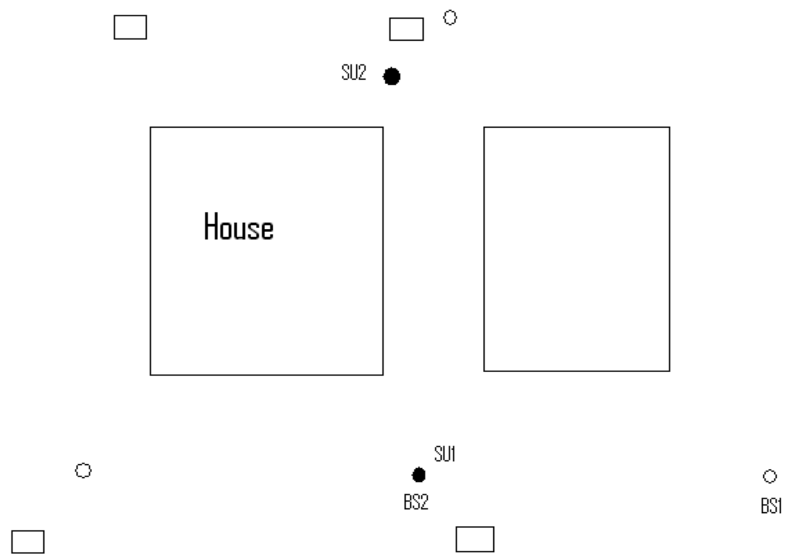

Figure 2: Camera Setup (Not to Scale)

This process was also done using a Nikon FE2 35mm SLR camera due to distortion problems that arose mid project.

Post Processing

The post processing of this project was, and I say this with pure exhaustion, the bulk of the work. With known systems to do the majority of grunt work such as the *Virtuozo Systems*™ for image edge detection and relation to stereo-photos available, this procedure would be greatly simplified. Due to monetary constraints as well as the design of using "everyday" technology to simulate the process, this was done by pages and pages of Excel spreadsheets.

To begin with, an examination of the camera itself was conducted. I found that the camera had a focal length of -0.06 meters and a pixel size of 2.6 x 10^{-6} meters for the Sony DSC-P8, and an equivalent focal length of -0.0845598 meters and 0.00001 meters resolution for the Nikon FE2 35mm SLR camera. At this time, points were measured off the photos in pixels using *Adobe Photoshop*™. The points were selected based on visibility in both photos and clarity of contrast. (i.e., corners of objects rather than assumed centers) These points or "image coordinates" were then adjusted to correlate their respective positions with regards to the center of the photo.

At this time, a relative orientation was conducted. Relative orientation is the process of minimizing parallax by eliminating discrepancies in the rotations of the photos individually. Parallax is described as "want of correspondence." the non-convergence of image rays at ground as seen in figure 3. It is easiest seen by placing your finger in front of your face looking at a point in the background about an arms length away and changing the eye with which you look at the finger. The finger will appear to move with respect to the background. This change in position (in the x direction (parallel to the line between the eyes)) is termed x-parallax, and is a direct measure of the depth of a point in the object space.

By solving the differential parallax formulae to minimize the parallax in the y-direction (orthogonal to the line between the eyes or camera), the two images can be rotated until they can be used to create a 3-D model of the object space. At this point there would be no y-parallax. In the figure below, the parallax vector is denoted with a **p**, where **r** and **l** are the image rays within each image.

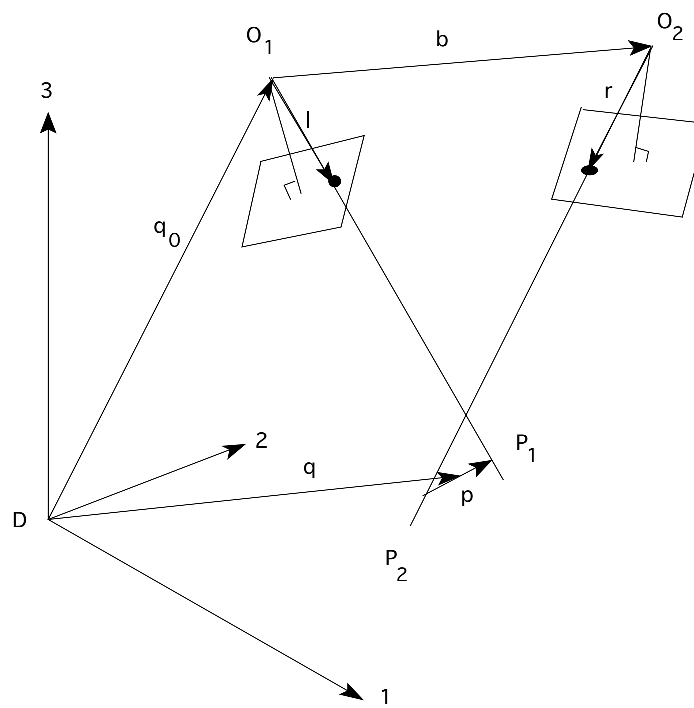

Figure 3: Parallax

The idea of a relative orientation is basically keeping one of the photos fixed and rotating the other until this y- parallax is minimized across the entire stereo image. In our project this was done by estimating the original rotations of the photographs as initial values and running a least squares adjustment on them. The rotations ω, ϕ, and κ can be seen in figures 4 below.

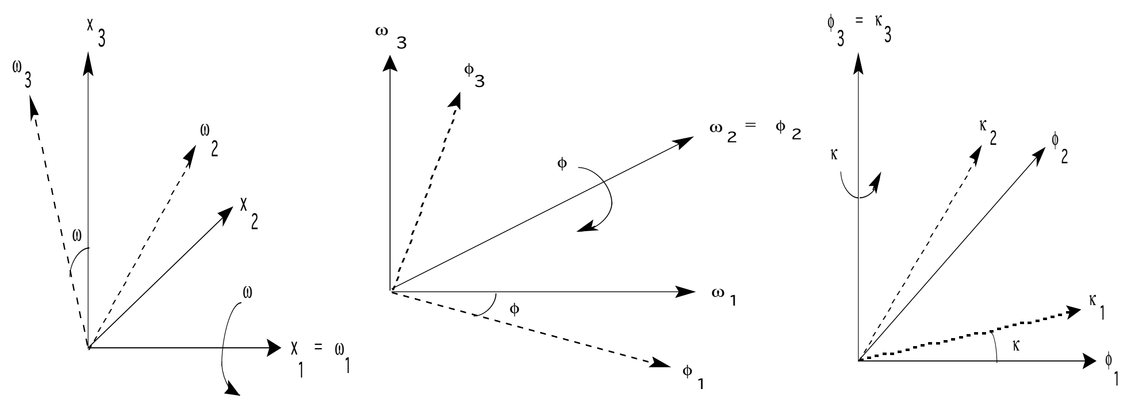

Figure 4: Rotations

As can be seen, these rotations are around the primary axis of the photos. When put into matrix format and multiplied they give a square matrix of cosines and sines as seen below. The complete rotation matrix is:

$$R_\kappa R_\phi R_\omega = M = \begin{bmatrix} m_{11} & m_{12} & m_{13} \\ m_{21} & m_{22} & m_{23} \\ m_{31} & m_{32} & m_{33} \end{bmatrix}$$

$$\begin{aligned}
m_{11} &= \cos\phi\cos\kappa \\
m_{12} &= \cos\omega\sin\kappa + \sin\omega\sin\phi\cos\kappa \\
m_{13} &= \sin\omega\sin\kappa - \cos\omega\sin\phi\cos\kappa \\
m_{21} &= -\cos\phi\sin\kappa \\
m_{22} &= \cos\omega\cos\kappa - \sin\omega\sin\phi\sin\kappa \\
m_{23} &= \sin\omega\cos\kappa + \cos\omega\sin\phi\sin\kappa
\end{aligned}$$

Having this initial rotation, the image coordinates for each photo were updated. This happened by taking these coordinates and the focal length and using matrix multiplication with the above rotation matrix. (i.e. the above matrix * $[u1, u2, -f]^T$) The following equation: δp_2, which is the model for the y-parallax shows how we obtained the differentiable variables for the **A** matrix in our adjustment, as well as finding the observations vector **m**. These values were used in iteration to provide the optimal corrections.

At this time, the iteration process began. Our photo measurements were based on a 17 point system for ease of compatibility in the spreadsheet. This gave us a 5X17 **A** matrix, one column for each rotation in each photo. (2 photos, with 3 rotations a piece, but with ω' which is held fixed), and one row for each observation. Using a least squares adjustment this process was iterated until a suitable convergence was met. At this time the photo coordinates were updated with the newly found relative rotations and sent off to perform an absolute orientation. See the Appendix.

$$\delta p_1 = \delta c'_1 - \frac{q_1}{q_3}\delta c'_3 - \frac{q_1 q_2}{q_3}\delta\omega' + \frac{q_3^2 + q_1^2}{q_3}\delta\phi' - q_2\delta\kappa'$$

$$-\delta c''_1 - \frac{q_1 - b_1}{q_3}\delta c''_3 - \frac{(q_1 - b_1)q_2}{q_3}\delta\omega'' + \frac{q_3^2 + (q_1 - b_1)^2}{q_3}\delta\phi'' + q_2\delta\kappa''$$

$$\delta p_2 = \delta c'_2 - \frac{q_2}{q_3}\delta c'_3 - \frac{q_3^2 + q_2^2}{q_3}\delta\omega' + \frac{q_1 q_2}{q_3}\delta\phi' + q_1\delta\kappa'$$

$$-\delta c''_2 - \frac{q_2}{q_3}\delta c''_3 - \frac{q_3^2 + q_2^2}{q_3}\delta\omega'' + \frac{(q_1 - b_1)q_2}{q_3}\delta\phi'' - (q_1 - b_1)\delta\kappa''$$

Figure 5: A matrix co-efficients (δp)

Absolute orientation is the physical orientation between the model generated from the 2 photos, and the real world at the time of exposure. While relative orientation only requires individual rotations for each photo to find the best match (and hence a model that is arbitrarily scaled and located in space), absolute orientation is used to find the best fit of the two models as the real world. To achieve the absolute orientation the scale factors λ and ρ need to be found. By using the camera locations and the rotated coordinates, these values were solved using the parallax equation below. (figure 3 shows the values)

$$\lambda \mathbf{l} = \mathbf{b} + \rho \mathbf{r} + \mathbf{p}$$

Using the rotated image points from the relative orientation and these scale factors, model coordinates in 3-D can be found. These coordinates will be used in the final outcome when model coordinates are transferred to ground co-ordinates. See Appendix. At this time a matrix was created based on initial rotation values similar to that of the relative orientation. However, only one is needed at this time since the 2 photos are now acting as a system, producing a single 3-D model. An A matrix was constructed using this rotation matrix, the locations of the 2 cameras, and the location of one known point. This point would be a simple GPS receiver or a staked property pin with known data. The known ground points were modified due to the scale factors found in the initial rotations and used as the observation vector in the iterations. Upon convergence, the orientation was applied to the initial measured coordinates and brought to ground.

Errors

The errors involved within the project were taken up on a need to solve basis. This project was set up on a theoretical basis, so knowing the mechanics of the equations and how it was supposed to work did not limit the errors. To begin with, I had amassed over 16 sheets in excel with over 400 cells a piece. Needless to say there were a few missed minus signs, as well as wrong equation parameters that took hours on hours to find. However, the biggest source of error originally was the camera.

Starting with the Sony digital camera, the project was in full effect. All field work completed and post processing in full motion, I was feeling confident. There was however a slight problem. None of the Absolute orientations would converge. It appeared that the majority of the Relative orientations would have quite a few iterations and some severe oscillations. The Absolutes were not having it however. It was not until later that we discovered that the camera was not stable in its calibration and could not be modeled. The camera had had basic calibration come time in the past, but its distortion parameters had not been modeled on that occasion.

By taking a window with a square glass columns and rows (image below), pictures were taken using the camera. These blocks of glass were also measured using a standard tape. The distances between the blocks with respect the center of the window were then calculated. Using the focal length, pixel sizes and coordinates of the corners of these window blocks, differences began to arise between actual distance and photo-measured distance. It was found that for each different photograph take from the digital camera, the center of the photo's distortion moved around. This caused each photo to have a unique distortion model. It is believed that this distortion is due to the camera having a variable focal length (i.e. it physically moves in and out to zoom) and that the lenses therefore must tilt and so find themselves in slightly different positions each time an image is taken. The attempts at modeling the original photo distortion showed these movements and irregularities. Equations used for the distortions were:

$$d = x - f \tan \alpha \quad \text{AND} \quad d' = d - \delta x_0 - x \frac{x}{f} \delta f - \left(1 + \frac{x^2}{f^2}\right) f \, \delta\omega$$

Figure 6: Blocked Window

The process was then redone using the Nikon 35 mm with much better results. There was still a distortion, but it was constant with each photo. This allowed for a model of the distortion to be created and applied to the photos. This lowered the errors and allowed for convergence. The model can be seen in the following figures.

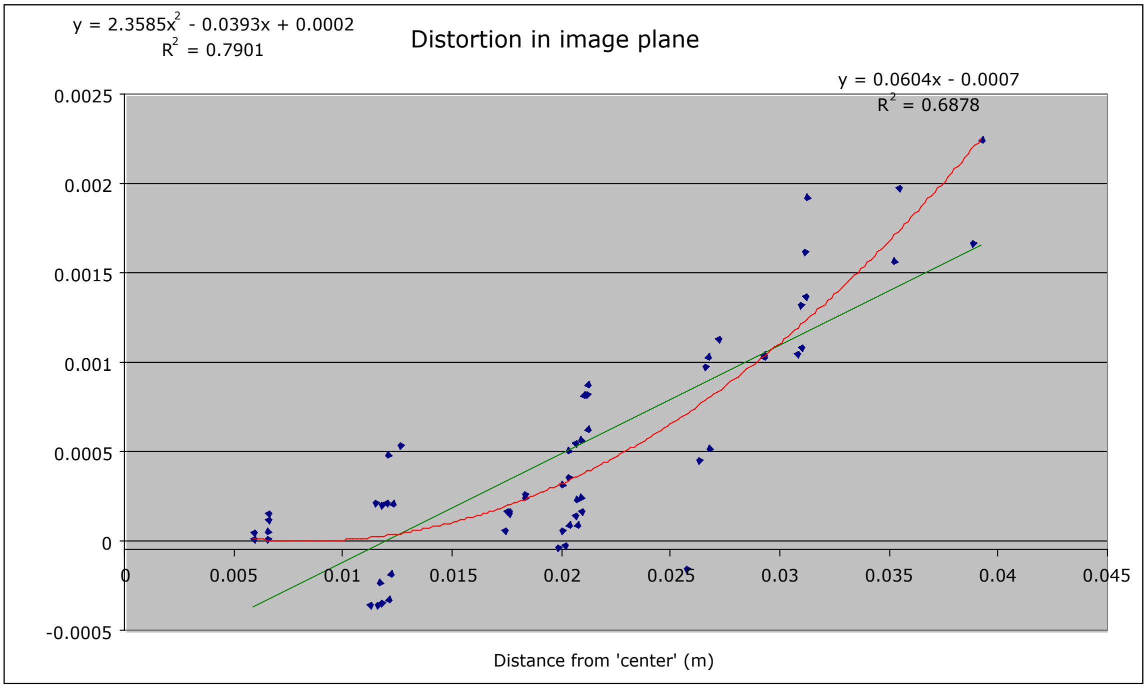

Figure 7: Distortion Model (red line)

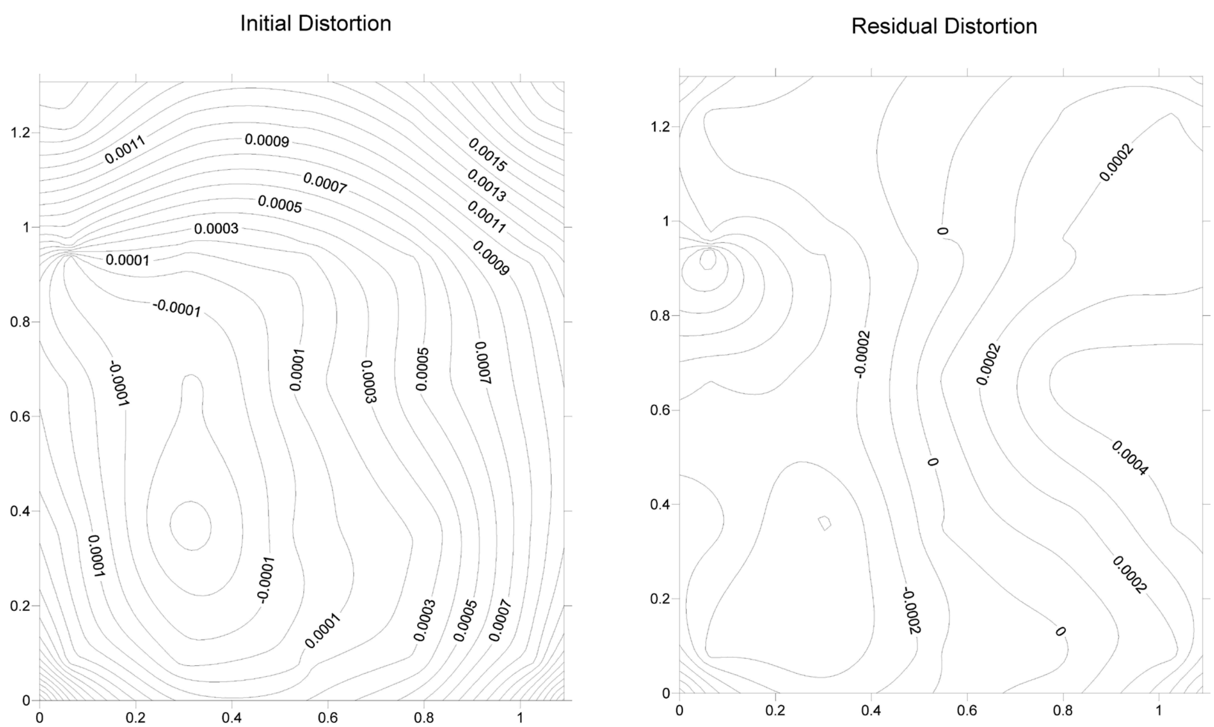

Figure 8: shows the distortion in the image before and after applying the computed distortion model. The residual distortion, i.e., the distortion that is not accounted for by the symmetrical distortion model, can be seen to have the effect of a tilt, indicating that the camera was not lined up to be exactly perpendicular to the plane of the window. This suggests that the distortion model is quite good for this camera, as the tilts will be resolved in the relative orientation.

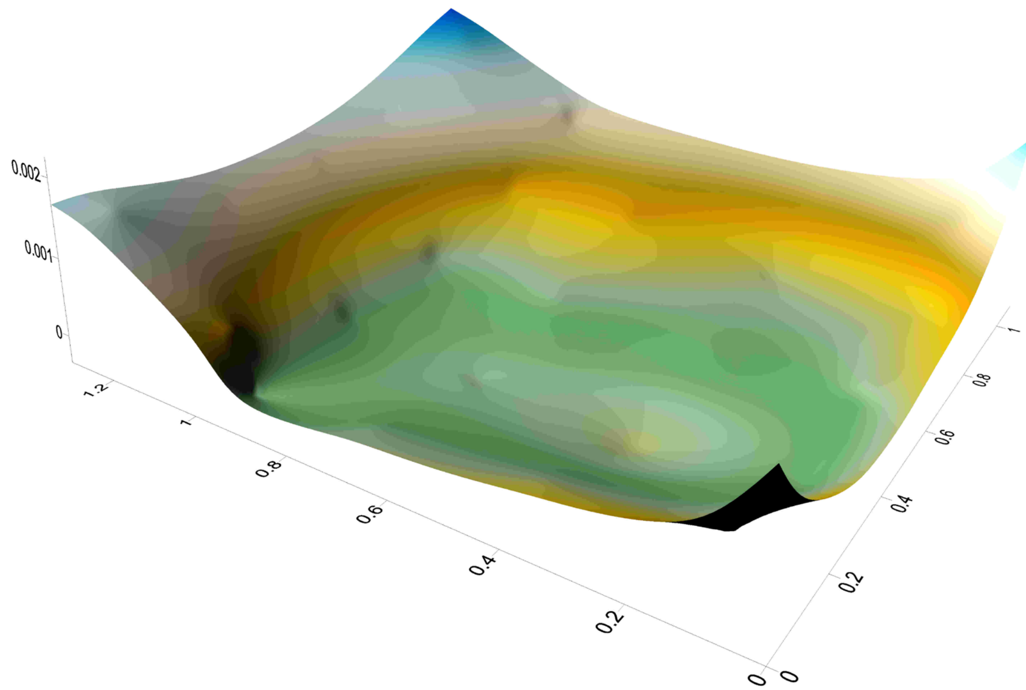

Figure 9: 3-D Distortion view (before model)

Conclusions

From the completion of this project I can say that overall it was a success. As can be seen in the following figure, the photos do not give results that would fit the standards of the mortgage survey; however they do show the capabilities of this process. As can be seen in the following figure, the points match closely at some points and are way off at others. But this being a project based solely on the ability to do the survey with "on-hand" technology and tools, it is not entirely horrible.

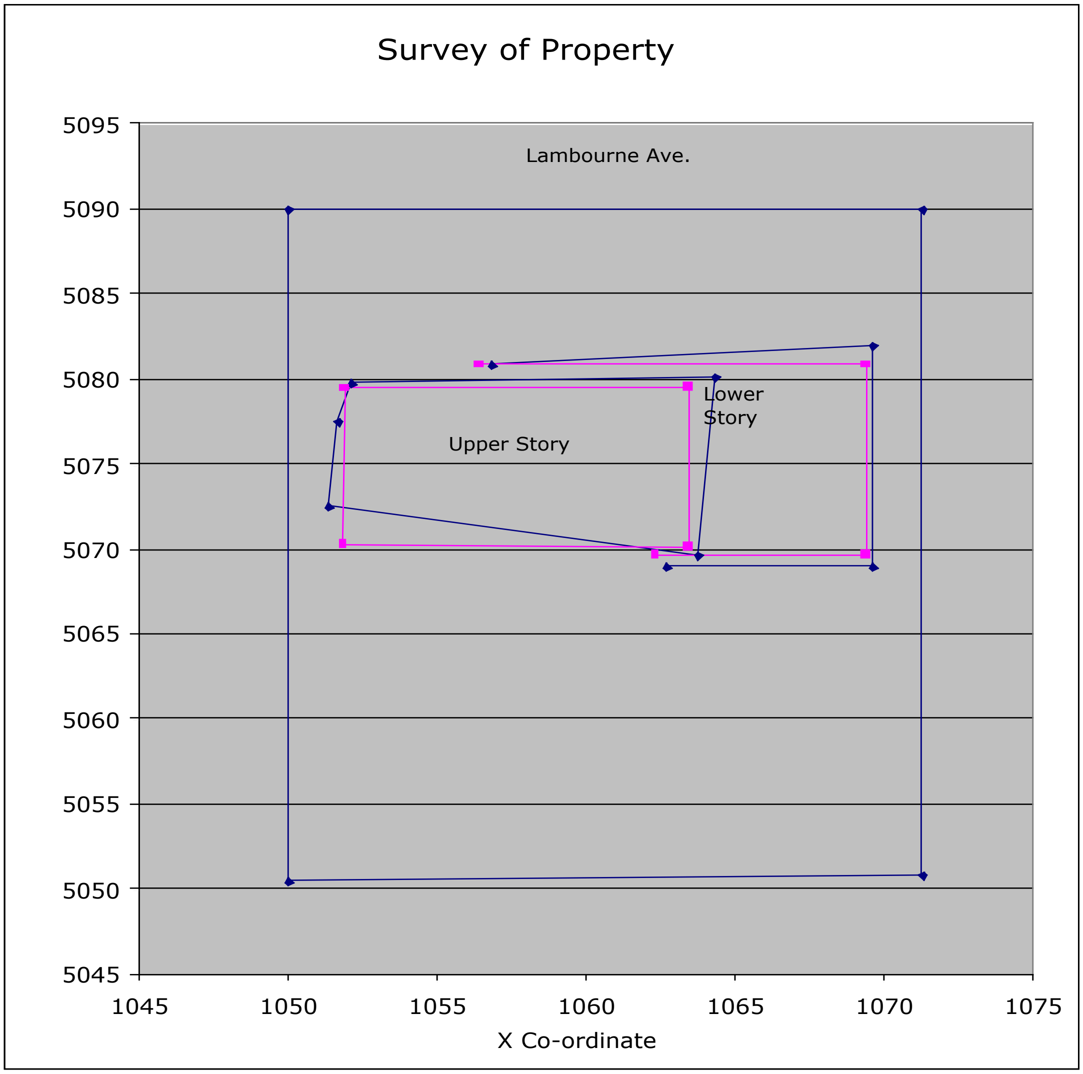

Figure 10: End results. Pink (Total Stations), Blue (Camera)

Some explanations of this are the photo locations. On the west side of the house there is about an 8 ft clearance between houses. This caused the 2 photos for that side to be shot at a rather steep convergence angle and with relatively few points in common. (See figure 11) The east side also had a similar problem with all common points being in a small area of the photo and therefore not getting enough of a scatter of points to effectively correct the rotations. (See figure 12).

Figure 11: High Convergence Angle Shots (West of House)

Figure 12: Low Coverage, i.e., minimal overlap (Ease of House)

Although these problems did occur, I believe the camera based survey is still a viable solution. Some may contest that this same project could easily be done with GPS and at a much faster more reliable way. I disagree. The housing situation as seen in this block leaves little spacing between the houses. The multipath in this area would be quite significant. The house that I surveyed also had significant tree coverage in both the front and back that would cause loss of signal.

The major fault of this project was additionally its major component, "using everyday technology". The technology we used in the field did not achieve the optimum results, yet neither did it completely fail. The digital camera proved to be a bust due to the distortion problems. Even though the data was not used, the camera was only 3.4 megapixels. While that would provide a basic solution, would it have sufficient resolution?

Human error also contributed. The spreadsheets were made by hand, equations were found to have mistakes, although checks and rechecks were performed, did I miss something? Perhaps a minus instead of a plus? Although I am assured that I did not miss anything, it is a possibility in that something could remain in the plethora of cells. Also done by the operator in this project was the finding of the model coordinates. The photos were put into an image viewer and the points were selected. These points were zoomed in as close to pixilation as possible while still retaining some contrast so that the points would be as close as they could. A half pixel discrepancy does not change the orientations enough to throw the results off, but it may cause the results to be a little poorer, especially if higher resolution imagery is available. These are the questions that must be addressed.

It is in my opinion that if you had a camera with few moving parts in the focusing, with an inbuilt GPS receiver you could achieve the standard if not better results. By having GPS coordinates of some kind within the photo (i.e. GPS and staking the property corners, perhaps with the camera's system.) for the control and basis of the absolute orientation, this procedure could be achieved by a single instrument with little to no set up. In addition the software such as the *Virtuozo Systems*™, which does both edge detection as well as orientation adjustments, could be available in a laptop computer on site for easy download and checking before returning to the office. Also there would be no need for control after the first photo pair was collected. As long as sufficient overlap existed, the coordinates found in the solution of the first pair could be control for the remaining photos, thus requiring GPS usage only where the signal is strongest.

In today's world this device already exists in the form of camera phones. Many phones nowadays are equipped with GPS technology, Bluetooth, and cameras with quite a few mega pixels of resolution. As the rate of mega pixels in digital cameras increase almost exponentially, (I've heard there are 13.1megapixel cameras on the market at present, and a 10 megapixel camera can be bought for under $1,000) the results of this experiment would only get better. The more technology advances in this area, the greater the realization of this technique can be. The surveyors who realize this could turn a low end margin type of work into something quite profitable with his/her costs incurred being solely the cost of the camera, the cost of the software and laptop, and his/her own time.

References

Hazelton, N.W.J., 2004. GS 400.02 Class Notes: Introduction to Photogrammetry. The Ohio State University.

Schenk, A.F., 1999. Digital Photogrammetry, Volume 1. Laurelville, OH: TerraScience.

Wolf, P.R., 2000. Elements of Photogrammetry, with applications in GIS. Boston: McGraw-Hill.

Appendix

InteriorInterior and Relative Orientations

Model 1

Left photo photo_2
Right photo photo_1

1 pixel = seconds
degrees
5.913E-05radians

Enter location of image points in each photo in the area

below, using pixel locations by row and column.

(As measured in PhotoShop)

	Left Photo		Right Photo	
Point ID	**u_1**	**u_2**	**v_1**	**v_2**
1	6852	3220	4650	2923
2	2164	2564	2362	2699
3	3672	3655	175	3536
4	4354	2679	5204	2452
5	4008	2679	4772	2520
6	3872	2293	4481	2093
7	4552	2090	5261	1642
8	3953	1811	5588	1402
9	3074	1682	3775	1628
10	2535	1887	3006	1992
11	3858	2603	3894	2487
12	4965	2325	6463	1774
13	2920	2855	3443	2881
14	1037	2910	1784	3083
15	3132	2614	3062	2602
16	3242	2220	3726	2165
17	3782	2923	3939	2861

Corrected to center of photos (in pixels)

u_1	**u_2**	**v_1**	**v_2**
3254	-760	1059	-441
-1434	-104	-1229	-217
74	-1195	-3416	-1054
756	-219	1613	30
410	-219	1181	-38
274	167	890	389
954	370	1670	840
355	649	1997	1080
-524	778	184	854
-1063	573	-585	490
260	-143	303	-5
1367	135	2872	708
-678	-395	-148	-399
-2561	-450	-1807	-601
-466	-154	-529	-120
-356	240	135	317
184	-463	348	-379

LL	30	4829	22	4844
UL	25	76	16	109
UR	7166	94	7164	120
LR	7169	4842	7162	4856
	7167.5	4835.5	7163	4850
	27.5	85	19	114.5
	7140	4750.5	7144	4735.5
	3570	2375.25	3572	2367.75
center	3598	2460	3591	2482

Final Solution

	Left	Right
omega	0	-3.3171
phi	39.60	-32.3705
kappa	-5.72	-0.0131
	7	

Absolute Orientation of Model

Model 1

Left Camera	photo_2
Right Camera	photo_1

Camera Locations

Photo No.	X	Y	Z	
1	1044.314	5103.989	99.749	XX
2	1073.588	5105.530	100.361	XX
3	1086.123	5103.760	100.580	
4	1045.316	5094.495	99.537	
5	1050.484	5062.045	99.858	
6	1050.484	5062.045	99.858	
7	1070.582	5057.155	100.289	
8	1070.582	5057.155	100.289	
Inst Pt.	1050	5090	100	
Control Pt.	1056.43	5080.842	101.68	XX

Ground Control Points / Model Co-ordinates

Point	X	Y	Z	x	y	z
Left Camera	1073.588	5105.530	100.361	0.000	0.000	0.000
Right Camera	1044.314	5103.989	99.749	29.321	0.000	0.000
Imaged Pt.	1056.432	5080.842	101.683	17.568	20.043	1.326

Camera Dist. 29.321

-0.0845598 focal length (meters)

1.00E-05 pixel size (meters)

Relative Orientation Solution (degrees)

	Left	Right
omega	0	-3.3171
phi	39.607	-32.370
kappa	-5.719	-0.0130

Iterations = 7

Photo Measurements

Point ID	Left Photo u1	Left Photo u2	Right Photo v1	Right Photo v2
1	6852	3220	4650	2923
2	2164	2564	2362	2699
3	3672	3655	175	3536
4	4354	2679	5204	2452
5	4008	2679	4772	2520
6	3872	2293	4481	2093
7	4552	2090	5261	1642
8	3953	1811	5588	1402
9	3074	1682	3775	1628
10	2535	1887	3006	1992
11	3858	2603	3894	2487
12	4965	2325	6463	1774
13	2920	2855	3443	2881
14	1037	2910	1784	3083
15	3132	2614	3062	2602
extra 16	2064	1728	2477	1971
extra 17	608	2384	1213	2682
old 16	3242	2220	3726	2165
old 17	3782	2923	3939	2861
centers	3598	2460	3591	2482

Corrected to center of photos (in pixels) / Corrected to center of photos (in meters)

Point ID		u1	u2	v1	v2	u1	u2	v1	v2
1		3254	-760	1059	-441	0.03254	-0.0076	0.01059	-0.00441
2		-1434	-104	-1229	-217	-0.01434	-0.00104	-0.01229	-0.00217
3		74	-1195	-3416	-1054	0.00074	-0.01195	-0.03416	-0.01054
4		756	-219	1613	30	0.00756	-0.00219	0.01613	0.0003
5		410	-219	1181	-38	0.0041	-0.00219	0.01181	-0.00038
6		274	167	890	389	0.00274	0.00167	0.0089	0.00389
7		954	370	1670	840	0.00954	0.0037	0.0167	0.0084
8		355	649	1997	1080	0.00355	0.00649	0.01997	0.0108
9		-524	778	184	854	-0.00524	0.00778	0.00184	0.00854
10		-1063	573	-585	490	-0.01063	0.00573	-0.00585	0.0049
11	XX	260	-143	303	-5	0.0026	-0.00143	0.00303	-0.00005
12		1367	135	2872	708	0.01367	0.00135	0.02872	0.00708
13		-678	-395	-148	-399	-0.00678	-0.00395	-0.00148	-0.00399
14		-2561	-450	-1807	-601	-0.02561	-0.0045	-0.01807	-0.00601
15		-466	-154	-529	-120	-0.00466	-0.00154	-0.00529	-0.0012
extra 16		-1534	732	-1114	511	-0.01534	0.00732	-0.01114	0.00511
extra 17		-2990	76	-2378	-200	-0.0299	0.00076	-0.02378	-0.002
old 16		-356	240	135	317	-0.00356	0.0024	0.00135	0.00317
old 17		184	-463	348	-379	0.00184	-0.00463	0.00348	-0.00379

XX Image point used for control is center of instrument.

Left Rotation Matrix

0.0000	0.7666	-0.0997	-0.6343
0.6913	0.0768	0.9950	-0.0635
-0.0998	0.6375	0.0000	0.7704

-93.0141	GC 1-2
90.0000	Model 1-2
183.0141	

Right Rotation Matrix

-0.0579	0.8446	0.0308	0.5345
-0.5650	0.0002	0.9983	-0.0577
-0.0002	-0.5354	0.0489	0.8432

23.2730	R to Im (Mod)
26.1983	R to Im (GC)
26.6867	L to Im (Mod)
30.0927	L to Im (GC)

Corrected for relative orientation rotations

Left Camera				Right Camera		Model Scale Factors		Resulting Parallax (m in object space)	
x1	x2	x3	y1	y2	y3	lambda	rho		
0.0782	0.0005	-0.0453	-0.0364	0.0005	-0.0772	294.4248	173.0501	0.0714	XX
0.0428	0.0033	-0.0742	-0.0556	0.0027	-0.0649	275.4801	315.1962	0.0371	
0.0554	-0.0064	-0.0647	-0.0729	-0.0051	-0.0544	206.4016	245.4004	0.0652	
0.0596	0.0038	-0.0604	-0.0317	0.0052	-0.0798	350.7263	265.1225	0.0477	
0.0570	0.0035	-0.0626	-0.0353	0.0045	-0.0776	343.3307	276.7931	0.0338	
0.0555	0.0072	-0.0635	-0.0376	0.0088	-0.0759	337.2010	282.0060	0.0447	
0.0606	0.0098	-0.0591	-0.0311	0.0131	-0.0797	350.8047	260.1201	0.0081	
0.0557	0.0121	-0.0629	-0.0284	0.0154	-0.0812	377.3698	292.3072	0.0476	
0.0489	0.0127	-0.0685	-0.0434	0.0134	-0.0719	325.0606	309.6734	0.0194	
0.0450	0.0102	-0.0719	-0.0500	0.0097	-0.0679	299.7356	317.0670	0.0252	
0.0557	0.0042	-0.0635	-0.0427	0.0048	-0.0729	315.4149	275.0604	0.0076	
0.0639	0.0077	-0.0565	-0.0216	0.0117	-0.0858	375.1532	247.1485	0.0166	
0.0489	0.0009	-0.0694	-0.0465	0.0010	-0.0707	310.0380	304.4980	0.0030	
0.0350	-0.0009	-0.0810	-0.0604	-0.0010	-0.0621	257.5959	336.0878	0.1176	
0.0503	0.0035	-0.0681	-0.0497	0.0037	-0.0686	294.4749	292.3963	0.0480	
0.0413	0.0114	-0.0748	-0.0544	0.0100	-0.0651	282.5179	324.5004	0.0082	
0.0315	0.0039	-0.0835	-0.0648	0.0029	-0.0590	237.8742	336.6264	0.0614	
0.0507	0.0075	-0.0674	-0.0440	0.0080	-0.0719	318.7931	298.9313	0.0051	
0.0555	0.0010	-0.0640	-0.0424	0.0011	-0.0733	316.9963	276.6367	0.0111	

1	scale				
degrees	Initial rotations	radians	Initial Rotation Matrix		
-0.4	Omega (X)	-0.0070	-0.9983	0.0522	-0.0265
-1.5	Phi (Y)	-0.0262	-0.0523	-0.9986	0.0056
177	Kappa (Z)	3.0892	-0.0262	0.0070	0.9996

Initial Model Co-ordinates

Left Camera	0.000	0.000	0.000	0	29.321	17.569
Right Camera	29.321	0.000	0.000	0	0.000	20.044
Imaged Pt	17.569	20.044	1.326	0	0.000	1.326

	Corrected Model Co-ordinates			Ground Control Co-ordinates		
Left Camera	0.000	0.000	0.000	1073.588	5105.530	100.361
Right Camera	-29.271	-1.534	-0.768	1044.314	5103.989	99.749
Imaged Pt	-16.529	-20.928	1.006	1056.432	5080.842	101.683

	dc1	dc2	dc3	dλ	dΩ	dΦ	dK	m
Left Camera	1	0	0	0.000	0.000	0.000	0.000	1073.588
	0	1	0	0.000	0.000	0.000	0.000	5105.530
	0	0	1	0.000	0.000	0.000	0.000	100.361
Right Camera	1	0	0	-29.271	0.000	-0.768	1.534	1073.585
	0	1	0	-1.534	0.768	0.000	-29.271	5105.523
	0	0	1	-0.768	-1.534	29.271	0.000	100.516
Imaged Pt	1	0	0	-16.529	0.000	1.006	20.928	1072.961
	0	1	0	-20.928	-1.006	0.000	-16.529	5101.770
	0	0	1	1.006	-20.928	16.529	0.000	100.677

Model Co-ordinates

	X1	-X3	X2
1	23.0163	13.3513	0.1231
2	11.8027	20.4446	0.8781
3	11.4324	13.3529	-1.2873
4	20.9125	21.1649	1.3500
5	19.5535	21.4819	1.2308
6	18.7199	21.3942	2.4458
7	21.2429	20.7305	3.4224
8	21.0212	23.7395	4.5307
9	15.8851	22.2565	4.1317
10	13.4793	21.5448	3.0787
11	17.5690	20.0438	1.3261
12	23.9746	21.1970	2.8981
13	15.1482	21.5320	0.2937
14	9.0229	20.8618	-0.2854
15	14.8022	20.0465	1.0567
extra 16	11.6703	21.1329	3.2252
extra 17	7.4969	19.8578	0.9563
old 16	16.1704	21.4792	2.3777
old 17	17.5898	20.2843	0.3109

left-right (X) away (Y) up-down (Z)
as seen from left camera position

Rotated Model Co-ordinates

0	-29.2713	-16.5287		0.0000	0.0000	0.0000
0	-1.5340	-20.9277		-29.2713	-1.5340	-0.7675
0	-0.7675	1.0056		-16.5287	-20.9277	1.0056

AT matrix

1	0	0	1	0	0	1	0	0
0	1	0	0	1	0	0	1	0
0	0	1	0	0	1	0	0	1
0	0	0	-29.2713	-1.5340	-0.7675	-16.5287	-20.9277	1.0056
0	0	0	0.0000	0.7675	-1.5340	0.0000	-1.0056	-20.9277
0	0	0	-0.7675	0.0000	29.2713	1.0056	0.0000	16.5287
0	0	0	1.5340	-29.2713	0.0000	20.9277	-16.5287	0.0000

AT * A matrix

3.0000	0.0000	0.0000	-45.8000	0.0000	0.2380	22.4618
0.0000	3.0000	0.0000	-22.4618	-0.2380	0.0000	-45.8000
0.0000	0.0000	3.0000	0.2380	-22.4618	45.8000	0.0000
-45.8000	-22.4618	0.2380	1571.9298	0.0000	0.0000	0.0000
0.0000	-0.2380	-22.4618	0.0000	441.9242	-390.8123	-5.8459
0.2380	0.0000	45.8000	0.0000	-390.8123	1131.6060	19.8673
22.4618	-45.8000	0.0000	0.0000	-5.8459	19.8673	1570.3295

(AT * A) inverse

0.7440	-0.0005	-0.0076	0.0217	-0.0003	0.0002	-0.0107
-0.0005	0.7450	0.0183	0.0106	0.0009	-0.0008	0.0218
-0.0076	0.0183	0.9985	-0.0001	0.0216	-0.0330	0.0011
0.0217	0.0106	-0.0001	0.0014	0.0000	0.0000	0.0000
-0.0003	0.0009	0.0216	0.0000	0.0037	0.0004	0.0000
0.0002	-0.0008	-0.0330	0.0000	0.0004	0.0024	-0.0001
-0.0107	0.0218	0.0011	0.0000	0.0000	-0.0001	0.0014

(AT * A)-1 * AT

0.7440	-0.0005	-0.0076	0.0931	0.2780	-0.0172	0.1629	-0.2775	0.0248
-0.0005	0.7450	0.0183	-0.2776	0.0927	-0.0150	0.2782	0.1622	-0.0033
-0.0076	0.0183	0.9985	0.0227	0.0017	0.0006	-0.0151	-0.0200	0.0010
0.0217	0.0106	-0.0001	-0.0199	0.0085	-0.0012	-0.0018	-0.0191	0.0013
-0.0003	0.0009	0.0216	-0.0006	0.0026	0.0279	0.0009	-0.0035	-0.0496
0.0002	-0.0008	-0.0330	-0.0017	0.0011	0.0355	0.0014	-0.0003	-0.0025
-0.0107	0.0218	0.0011	-0.0084	-0.0199	-0.0005	0.0191	-0.0018	-0.0006

x vector		degrees	Corrected Values			Adjusted Rotation Matrix	
1074.5324	dc1		1074.5324				
5104.7426	dc2		5104.7426				
100.4456	dc3		100.4456				
0.0731	dl		1.0731				
0.0012	dW	0.0697	-0.3303	-0.0058	-0.9981	0.0574	-0.0215
0.0050	dF	0.2847	-1.2153	-0.0212	-0.0575	-0.9983	0.0045
-0.0052	dK	-0.2970	176.7030	3.0840	-0.0212	0.0058	0.9998